UDC 621.777.4

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ANALYSIS OF STRAINED STATE OF METAL- AND WOODWORKING TOOLS AS A RESULT OF PLASTIC STRAIN TECHNIQUES

The article outlines the results of the research into the design of cutting tools composed of two metals with different properties. The research proves their applicability in various technological operations of metal and wood processing.

Introduction. The axial (point) cutting tool is one of the most applicable in metal- and wood working. The tool is made of costly high-alloy steel or hard alloys. This fact makes the problem of reducing the material consumption by means of their bimetallic or compound manufacturing very essential.

The research staff of the Physical-Engineering Institute of Belarus NAS are elaborating methods for manufacturing bimetallic point cutting tools composed of working (cutting) steel (P6M5 steel grade) and shank end (40X steel grade). The methods involve hot plastic strain operations in profile matrix, where straining of clearance grooves is accompanied by firm permanent joint of the components of a bimetallic tool. In some cases, when a large-size tool (a drill, a reamer bit, a milling cutter) of 30 mm diameter is manufactured, it is appropriate to apply a tool assembly in which the body represents a hollow cylinder put on a rod made of construction steel. This being the case, for high-speed or other tool steel saving purposes the body is manufactured by the method of hot extrusion on the workholder through the profile matrix. For this process to run effectively, it is necessary to analyze the strained state of a workpiece under plastic strain. This paper dwells upon the technique of assessing the workpiece strained state as well as upon the results of the strained state analysis of a large-size cutting tool workpiece.

Technique of assessing the strained state of a cutting tool as a result of plastic deformation. To define basic parameters and characteristics of the pressing process under analysis or design, different techniques are applied. Thus, to obtain data about the strained state of pressed metal such experimental research technique as coordinate grid technique is applied which is good for both modelling and technological conditions of pressing [1].

The essence of the coordinate grid technique is as follows: a workpiece is divided into two equal semicylinders in one of the profile symmetry planes. The parting faces are then covered by a coordinate grid, i.e. longitudinal or cross-cut grooves which are 0.25–1.00 mm deep and wide (depending on the sample size). These grooves form squares or rectangles. The grid-forming grooves are filled by wires or fire-resistant paste. The grid blocks are measured and photographed. Then the two parts of a workpiece are put together and pressed as a whole metal body. After pressing the parts are separated again and the strain-distorted grid is measured.

Since the surface of the semicylinders is a symmetry plane, their simultaneous symmetrical strain cannot cause shearing stress in this plane, their physical state being equal. The degree of distortion of the workpiece parting plane can serve as a qualitative index of sectional plane matching to the main plane of stress-strain state [2]. This also allows to identify the character and quantitative indices of the strain.

The method of compound samples can be applied when a sample under test is made of discs or concentric layers of tested metal as well as of components having other shapes [3].

The insertion method consists in covering the surface layer of the sample with pieces of metals having approximately equal viscosity in pressing conditions [4].

The structural method involves study of macro- and microslices of certain parts of longitudinal and cross sections of the pressed sample together with press residues.

The photomechanics method, or photoelastic method [5, 6], makes it possible to identify certain regularities of metal flow during pressing processes similar to plane-strain condition.

The hardness method and structural method are not applicable as during actual technological process the strain occurs at temperatures exceeding recrystallized threshold.

It is most appropriate to study the strained state of the pressed workpieces by the coordinate grid technique. At the same time the complicated configuration of the cutting tool must be taken into consideration since the tool can have screwed cutting edges and be both solid and hollow, etc. The technique suggested below has been elaborated with due regard to all these specific features.

Semicylinders (Fig. 1, *a*, *б*) with cells of height H_0 and width A_0 on their side walls are put into a thin-walled glass (Fig. 1, *a*). The end faces of the semicylinders are covered with a grid forming concentric semicircles of R_1, R_2, …, R_n radii and 10 radial marks which divide the semicircles into 10 sections, i.e. angle $\gamma = 18°$.

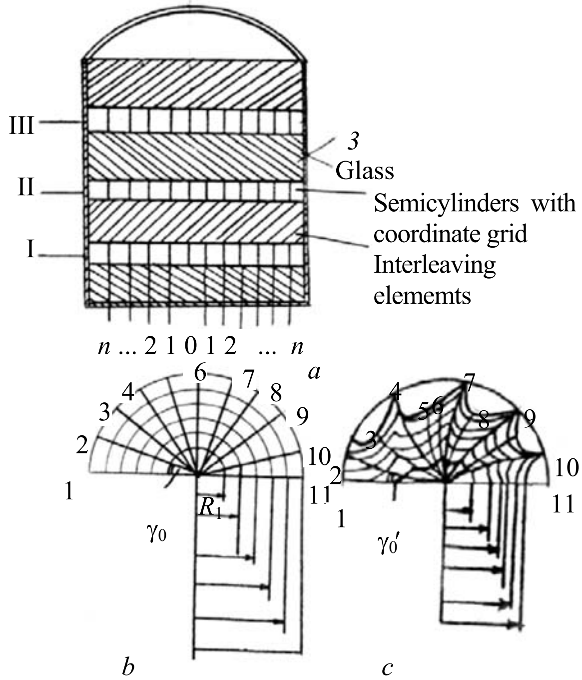

Fig. 1. Outline drawing of a compound workpiece to analyze the strained state of a large-sized cutting tool: *a* – thin-walled glass with semicylinders; *b* – parameters of coordinate grid on the semicylinder end face; *c* – coordinate grid after straining

The semicylinders are put into the glass interleaved with some elements without coordinate grid. The second part of the sample looks the same as the one described one. The marks of the coordinate grid are filled with chalky powder. The suggested structure of the sample ensures both parts to be separated after straining. Taking measurements of coordinate grid cells before and after straining makes it possible to assess the strained state by the following parameters.

1) Local stretches in different sections by sample height (sections I, II, III) and over various distances from the sample axis (sections 1, 2, 3 …, *n*):

$$\lambda = \ln \frac{H_0}{H_1}, \tag{1}$$

where H_0 and H_1 are cell heights before and after straining respectively.

2) Lateral strains (distributed over the same sections as λ):

$$\beta = \ln \frac{A_0}{A_1}, \tag{2}$$

where A_0 and A_1 are cell widths before and after straining respectively.

3) Radial strains in different areas of crosssection and over the sample height:

$$\delta = \ln \frac{R_n - R_{n-1}}{R_n^{'} - R_{n-1}^{'}}, \tag{3}$$

where non-stroked radial parameters are those before straining and stroked radial parameters are those after straining.

4) Twist angle of radial lines (this parameter is to be determined only for screw tools) over various distances from the workpiece axis (i.e. over R_1, R_2, R_3, …, R_n distances) and over sections of various heights I, II, III:

$$\begin{aligned} \gamma_n &= f(\text{I}, \text{II}, \text{III}, ..., N); \\ \gamma_n^{'} &= f(1, 2, 3, ..., n). \end{aligned} \tag{4}$$

Analysis of the strained state of a large-sized cutting tool. Initially, to analyze the strained state of a large-sized cutting tool round pierced billets made of P6M5 high-speed steel were used. The above described technique of coordinate grid was applied to analyze the plastic strained state of the workpieces, the grid cell size being 2×2 mm. The part-welded workpiece parts with coordinate grids on their diametral planes were subjected to press extrusion at 1,320 K (1,050°C) which is the optimal temperature for P6M5 steel. The range of selected strain degree was 50–70%.

The strained coordinate grid was measured with optical microscope accurate within 0.1 mm.

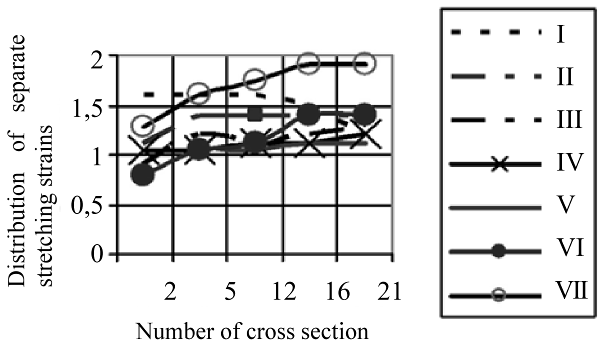

Fig. 2. Distribution of separate stretching strainsin the cutting tool

The analysis of experimental plastic strain data of cutting tool workpieces with overall strain degree of 80% reveals that separate stretching strains $\ln(b_0/b)$ are distributed rather evenly over the length. Certain minimization of separate stretching strains can be observed in periphery layers of a workpiece which are in the nonstationary flow stage of the extrusion process. Outer workpiece layers undergo smaller stretching strain which is attributable to different contact friction conditions of central and periphery layers.

The maximum radial strains $\ln(a_0/a)$ are found in the layers adjacent to outer surface (V-VI and VI-VII). The reason for this is the external friction which causes extra shear strain and stretching strain in surface layers – and hence the increasing separate compression strain.

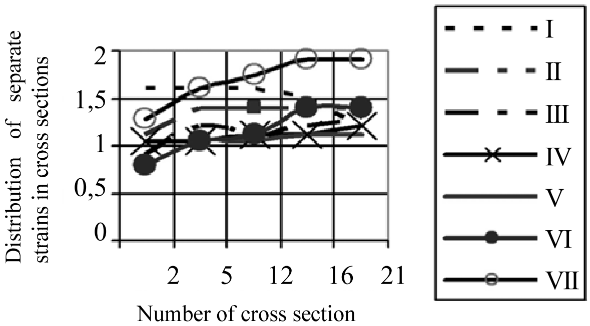

Fig. 3. Distribution of separate radial strains in the cutting tool

The exposed face of workpiece moving to press-tightening, the radial strains increase and reach their peak value in the press-tightening area.

Conclusion. The study of the strained state of the cutting tool workpieces shows that the irregularity of separate strains is rather insignificant both over the length and the section of extruded workpiece. Therefore, the selected strain degree being 80% or less, the straining of a workpiece is carried out in the stationary mode without development of micro- and macrocracks. This process can ensure manufacturing of high-quality durable tool.

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Received 14.03.2012